U.S. Regional Update

2013 International Workshop on EUV Lithography

Presented by Greg Denbeaux
CNSE

Resist-outgas testing at NIST

S. B. Hill, C. Tarrio, B. Berg, N. Faradzhev, S. Grantham and T. B. Lucatorto

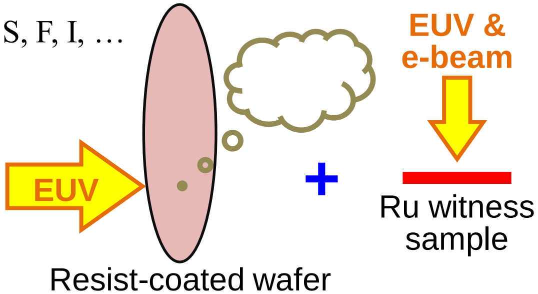
- NIST resist-outgas testing update
  - 2 customer resists tested since SPIE (3/11/13)
  - 23 total customer resists tested to date
  - All have passed CG
  - None have shown significant non-cleanables with XPS

- Ongoing work
  - Scaling of outgas-test CG with time & resist dose
  - Identifying sources of inter-facility discrepancies
  - Optimizing & validating relevance of “non-cleanables” portion of outgas test
  - Verifying EUV / e-beam correlation for “non-cleanables”

Three strategies to study non-cleanables

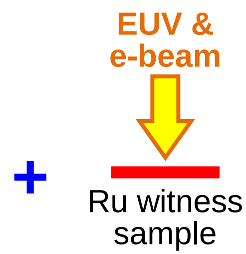
Witness sample in resist outgassing

- EUV resists with S, F, I, …
- Vary dose & time
- *Record RGA*



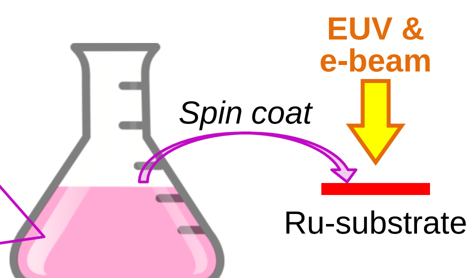
Witness sample in admitted gases

- Species with S, F, I, …
- Pure hydrocarbon
- Vary pressure & dose



Spun films with specific chemistries: S, F, I, …

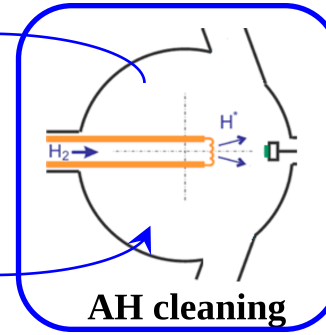
Polymers designed with non-cleanable elements (S, F, etc) in specific chemical forms.



AH cleaner *in situ* with XPS

(coming soon)

XPS *before* and at regular intervals *during* AH cleaning.



Characterization of EUV/e-beam exposures

- Composition: C & non-cleanables
- AH cleaning rates: C & non-cleanables
- Correlation with outgas RGA

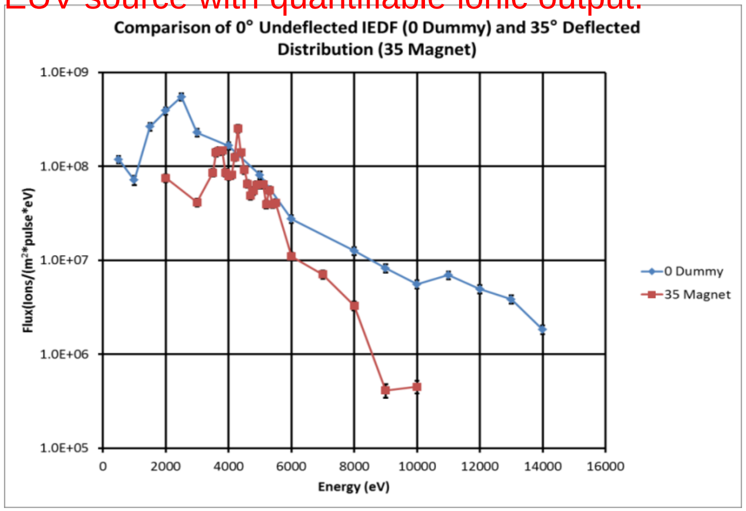
Magnetic Ion Mitigation and Hillock Formation

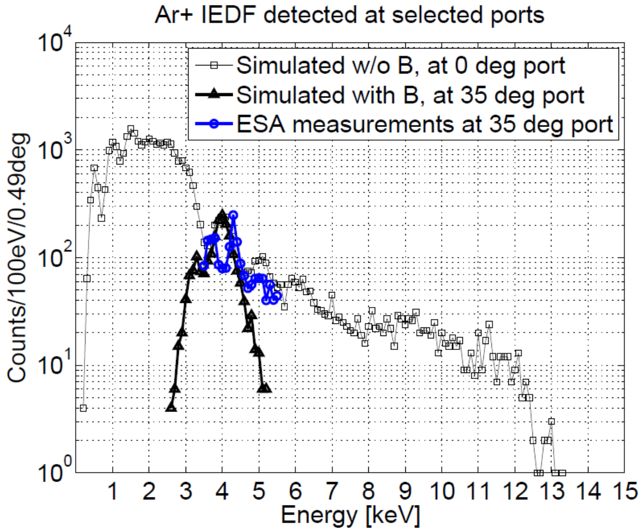
Magnetic Mitigation of High-Energy Ions in an EUV Source

Strong permanent magnet inserted in front of EUV source. Magnet modeled in COMSOL, particle trajectories simulated in MATLAB. Ionic output of source measured with Electrostatic Energy Analyzer (ESA). Experiment procedure below.

1. Without magnet, use ESA to measure head-on ion energy distribution function (IEDF).
2. Given initial IEDF, Simulation predicts IEDF at various angles with magnet present.
3. Magnet is inserted into chamber. IEDF is measured at an angle (35° shown) and compared to simulation.

Simulation predicts strong mitigation, which is confirmed by experiment. Simulation can be used for any magnet topology in any EUV source with quantifiable ionic output.



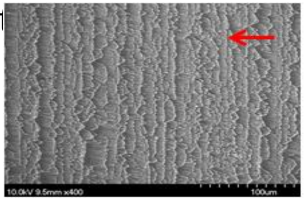


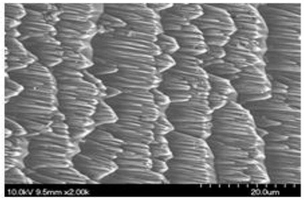
Hillock Formation on Sputtering Targets for EUV Mask Blanks

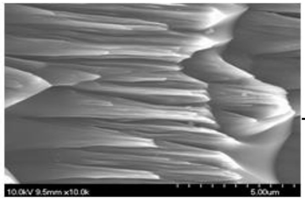
Hillocks form on sputtering targets for mask blanks; these hillocks later cause defects on deposited substrates.

Hillock formation was investigated as a function of incident ion angle and target material.

Hillocks appear to occur mostly on Si. When they appear on Ru targets, they are at locations of Si impurities on the Ru







Hillocks occur at larger ion angles for Si. In agreement with SRIM prediction: Y(θ,E)/Y(0,E) increases with θ.

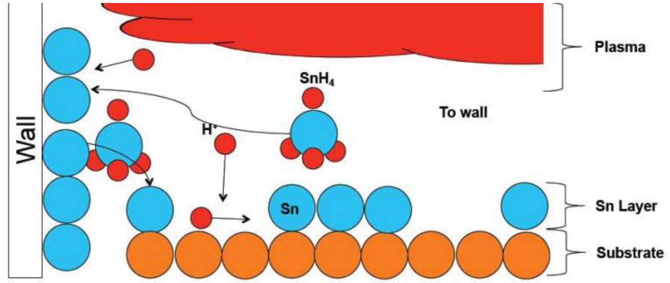
Can be removed by sputtering at 0° ion angle.

At left: Sintered Si surface, E=600eV, θ=75° exposed for t=6 hours.

Sn Cleaning by Hydrogen Plasma Exposure

Plasma produces H radicals, which bond to Sn and form SnH_4 (gas).

Etching is increased with radical production. However, chamber size (and cleanliness) and substrate size are limiting factors, as SnH_4 can dissociate upon collision and re-deposit.



Plasma Parameters and Environmental Conditions:

Etching also measured as function of various parameters (pressure, flow rate, temperature, contamination, etc).

Enough flow is needed to blow away SnH_4 before it decomposes without blowing away too many H radicals.

Higher temperatures lower etch rates, since SnH_4 can more easily dissociate at higher temperatures.

The only air contaminant to affect etching is oxygen, which eats up H radicals.

Ideal plasma parameters: Low T_e (fewer dissociating collisions), High n_e (more radical production).

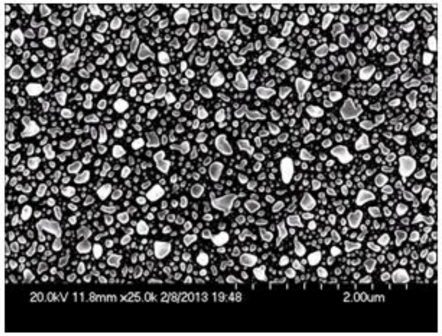
Recent Experiments:

Full Etching of dummy collector demonstrated for 20nm and 50nm of Sn deposition. Etching measured on Si witness plates.

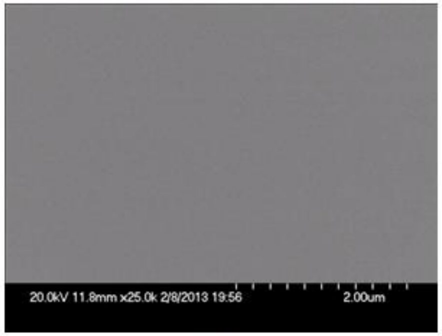
Etch Rates range from 0.75 nm/min to 1.33 nm/min, based on position (n_e changes based on position).

Etching removes Sn while not appearing to significantly roughen any exposed Si.

SEMs from 20nm Experiment Witness Plate



(a) Deposited

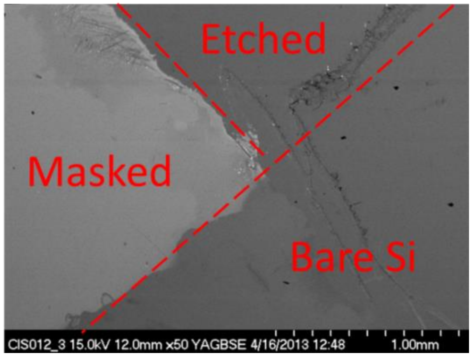


(b) Etched

Backscattered Electron (BSE) detector detects material differences.

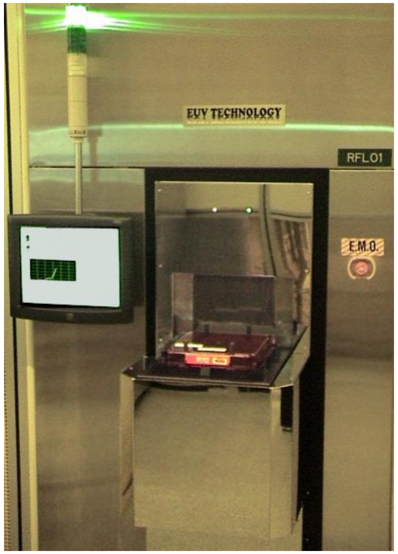
Etched portion of witness plate appears identical to bare Si. Masked portion (covered in Sn) is different.

BSE SEM from 50nm Experiment



EUV REFLECTOMETER

- Recipient of 2005 R&D 100 award
- Installed for over 12 years worldwide
- Fully automated user friendly operation
- Continuously improving performance - Improved software, laser, and speed.

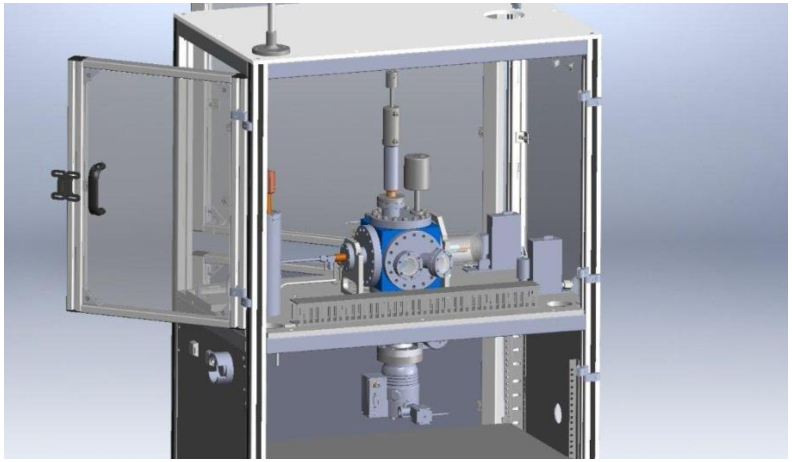


EUV RESIST OUTGASSING TOOL

- Measures the contamination of optics from resist outgassing by using EUV (Extreme Ultraviolet) photon exposure, or alternatively by using electron beam (e-gun) exposure
- EUV Tech has successfully delivered 3 resist out-gassing tools.
- Two of them have been ASML certified
  - Third one in the certification process

EUV HYDROGEN RADICAL CLEANER

- Streamlined witness sample transfer process between resist outgassing tool and hydrogen cleaner
- Cleaning rate ~ 3 nm/hour
- Small footprint 36” x 24”
- Controlled and interlocked N2 and H2 flow



Evolution of Plasma Cleaning of Vacuum Chambers

- 1990's: Original development to decontaminate diffusion pump oil from electron microscopes

- 2000's: Plasma cleaning of SEMs becomes *de facto* standard for advanced e-microscopy

- 2011: XEI develops plasma cleaning system in form factor of TEM wand

- 2013: XEI Scientific delivers first plasma cleaning system designed specifically for EUVL applications

PHYSICS OF PLASMAS **20**, 053105 (2013)

Laser produced plasma sources for nanolithography—Recent integrated simulation and benchmarking

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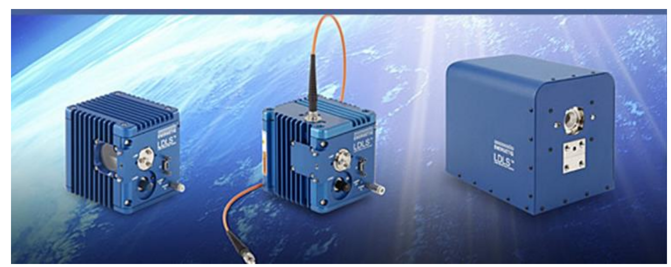
(Received 22 March 2013; accepted 1 May 2013; published online 21 May 2013)

Photon sources for extreme ultraviolet lithography (EUVL) are still facing challenging problems to achieve high volume manufacturing in the semiconductor industry. The requirements for high EUV power, longer optical system and components lifetime, and efficient mechanisms for target delivery have narrowed investigators towards the development and optimization of dual-pulse laser sources with high repetition rate of small liquid tin droplets and the use of multi-layer mirror optical system for collecting EUV photons. We comprehensively simulated laser-produced plasma sources in full 3D configuration using 10–50 μm tin droplet targets as single droplets as well as, for the first time, distributed fragmented microdroplets with equivalent mass. The latter is to examine the effects of droplet fragmentation resulting from the first pulse and prior to the incident second main laser pulse. We studied the dependence of target mass and size, laser parameters, and dual pulse system configuration on EUV radiation output and on atomic and ionic debris generation. Our modeling and simulation included all phases of laser target evolution: from laser/droplet interaction, energy deposition, target vaporization, ionization, plasma hydrodynamic expansion, thermal and radiation energy redistribution, and EUV photons collection as well as detail mapping of photons source size and location. We also simulated and predicted the potential damage to the optical mirror collection system from plasma thermal and energetic debris and the requirements for mitigating systems to reduce debris fluence. The debris effect on mirror collection system is analyzed using our three-dimensional ITMC-DYN Monte Carlo package. Modeling results were benchmarked against our CMUXE laboratory experimental studies for the EUV photons production and for debris and ions generation. [http://dx.doi.org/10.1063/1.4807379]

Energetiq's Products

ENERGETIQ

- High-brightness, long-life light source products
  - 1nm to 2000nm wavelength
- Product Applications
  - EUV Lithography and Metrology
    - Semiconductor Manufacturing
  - Soft X-Ray
    - Biological Imaging and Microprobe
  - UV/Vis/IR Imaging and Analysis
    - Spectroscopy
    - Inspection and Metrology



EQ-10 EUV Product Line

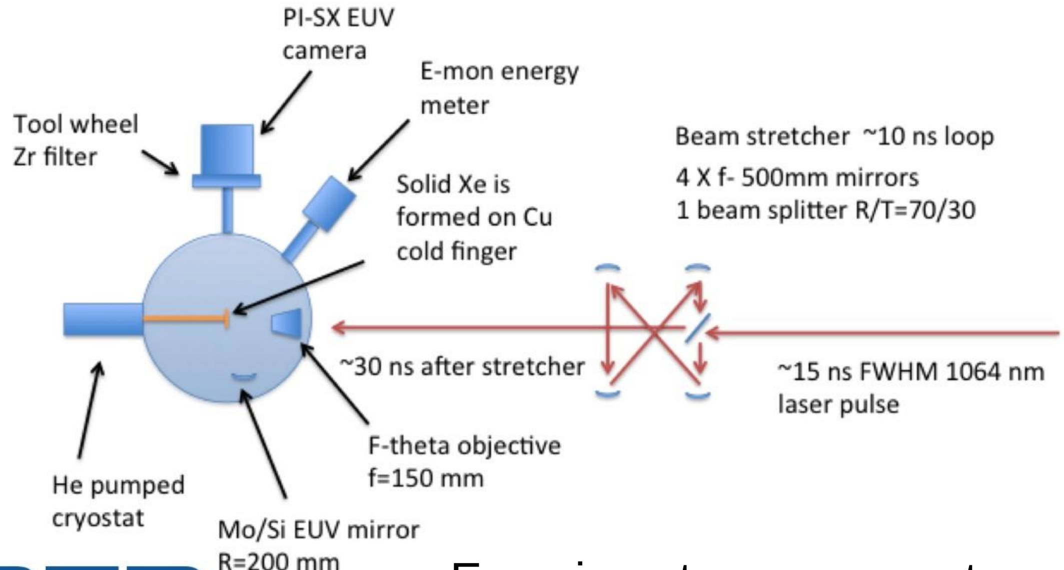
Typical Performance*	EQ-10	EQ-10HR	EQ-10HP
Power 2π (13.5nm±1%)	10W	2W	20W
Plasma Size (FWHM)	400um	1.6mm	400um
Maximum Brightness	5W/mm^2-sr	NA	8W/mm^2-sr
Repetition Rate	2kHz	10kHz	2kHz
Plasma Size Stability (σ)	<4μm		<4μm
Spatial Stability Position(σ)	<6μm		<6μm
Pulse-Pulse Stability	~2%		~2%

***Performance values are typical. Actual values depend on customer's particular operating conditions which vary by application.**

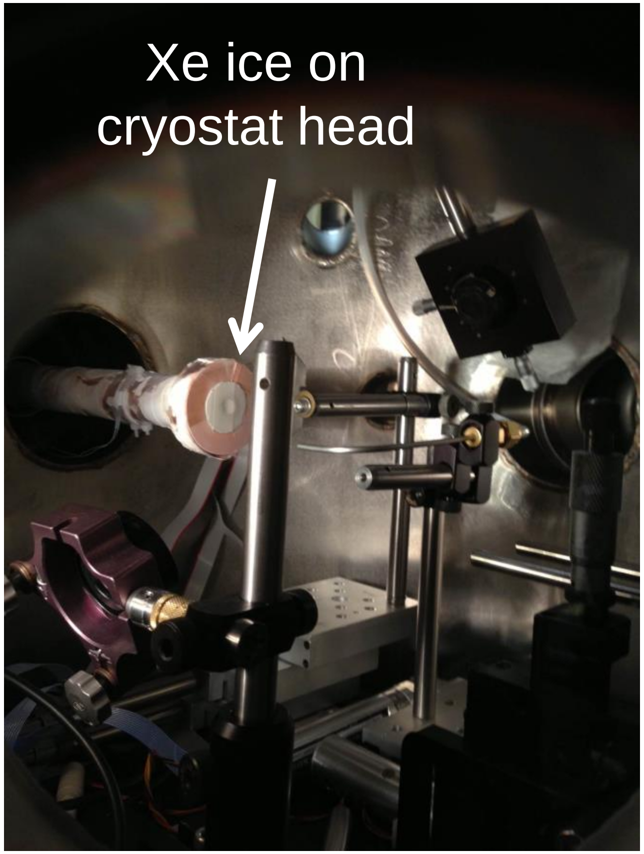
UCSD's current activities support actinic metrology (13.5 nm) LPP light source development at KLA-Tencor

M. S. Tillack and A. J. Effenberger

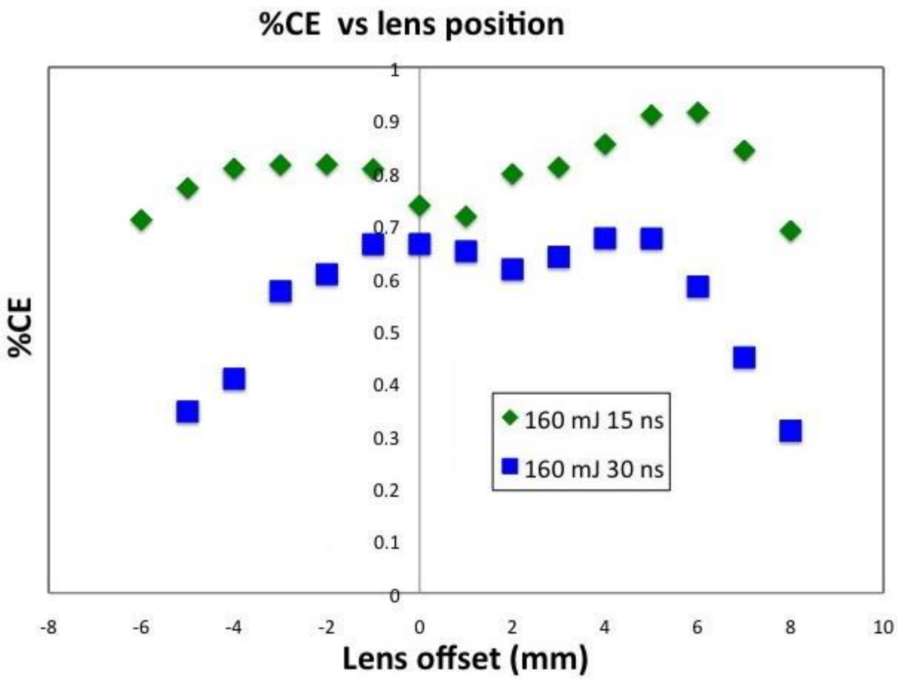
- Nd:YAG lasers on Xe ice targets
- Main research thrust involves long-pulse performance (CE, DER size)
- Production of, and laser interactions with ice is a special challenge

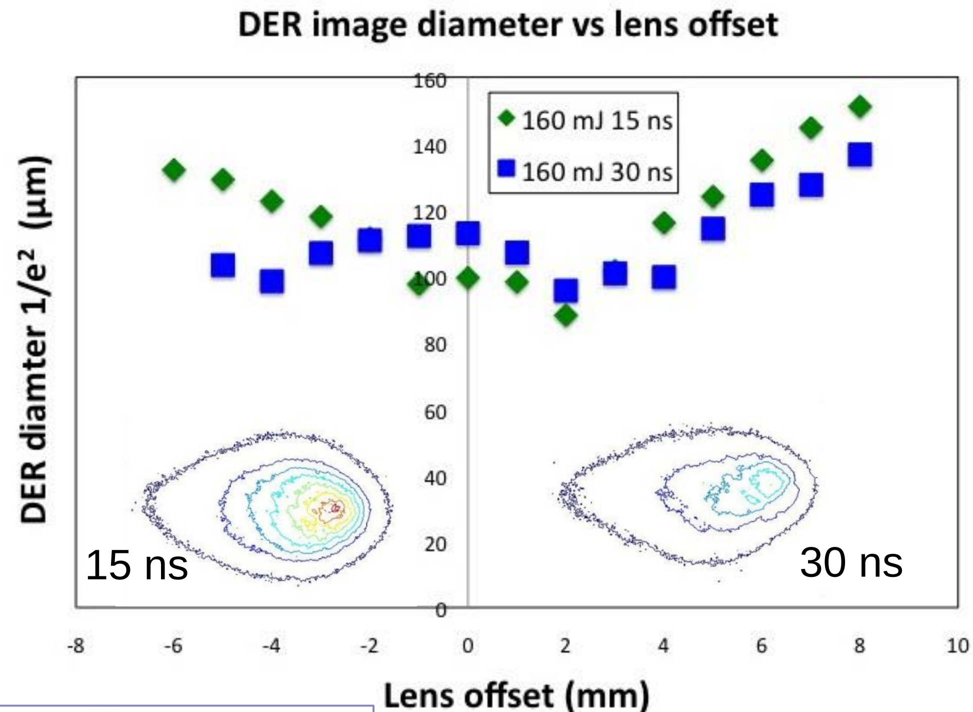


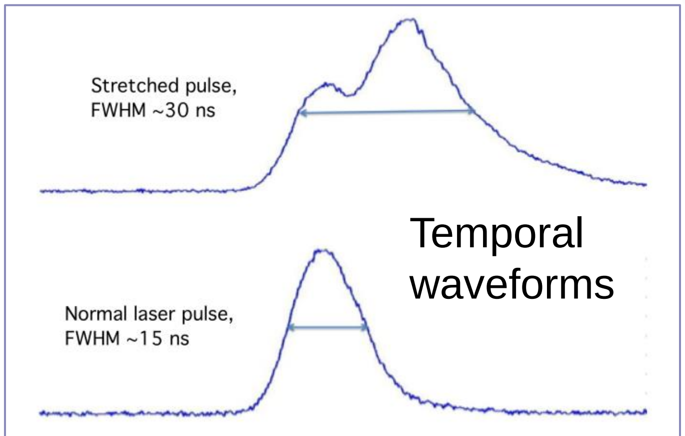
Experiment arrangement



Results show similar emitter size and only 10-20% reduction in conversion efficiency for longer pulses





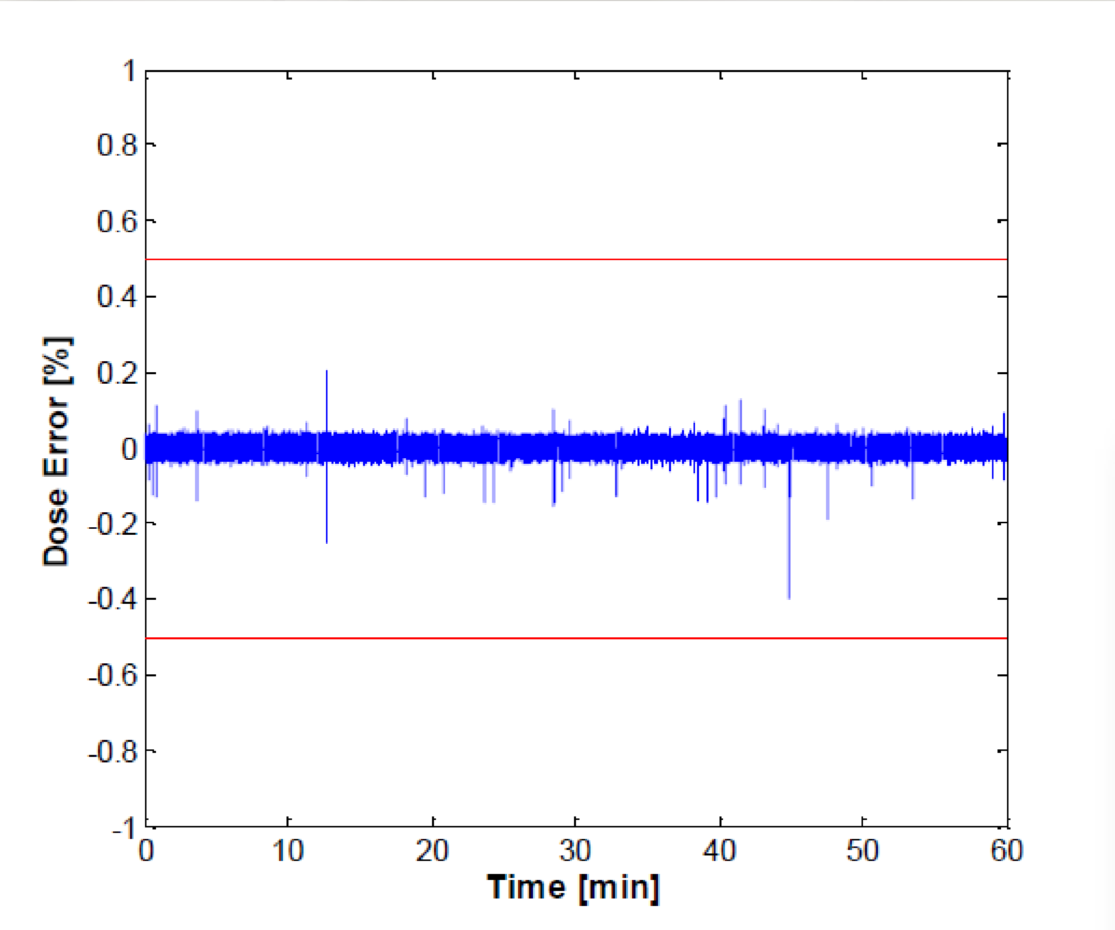


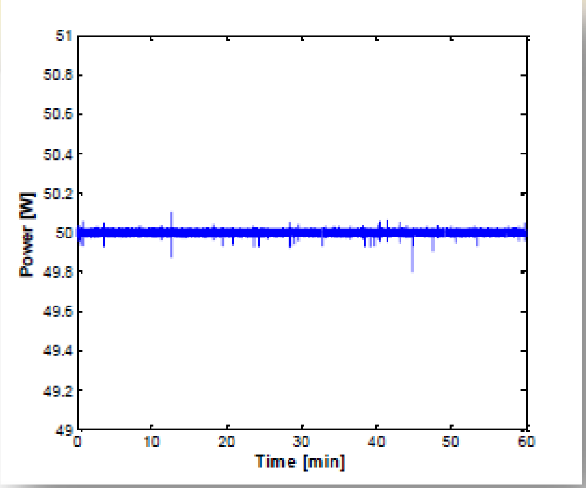
UC San Diego

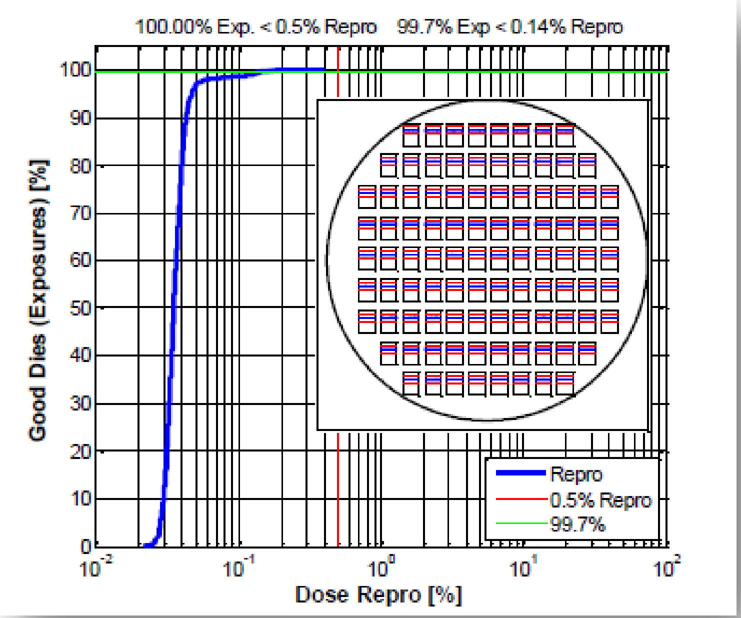
CER Center for Energy Research

50W EUV Power with <±0.5% Dose Stability MOPA Prepulse Mode of Operation

Dose control within spec over 1 hour run







Die Yield Exceeds 99.7%

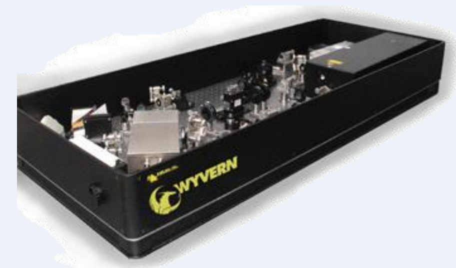
EUV ERC Overview

Tabletop EUV Lasers

- High Average Brightness and High Pulse Energy
- λ = 10 – 47nm

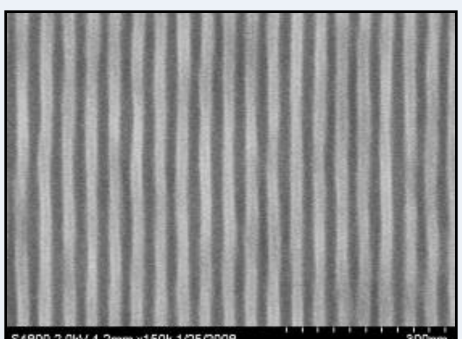
Two complementary compact source technologies

High Harmonic Sources



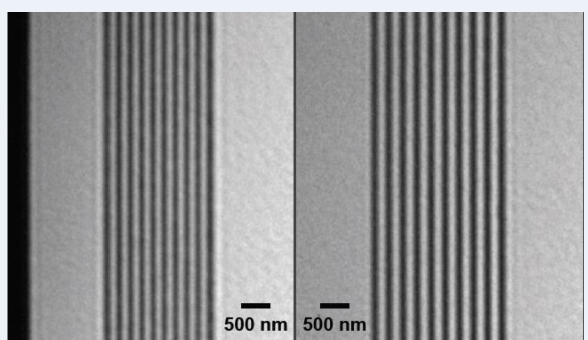
- High Average Brightness
- High Rep Rate (1 – 100kHz)
- λ = 3 – 30nm

High resolution EUV printing with high sensitivity and low LER

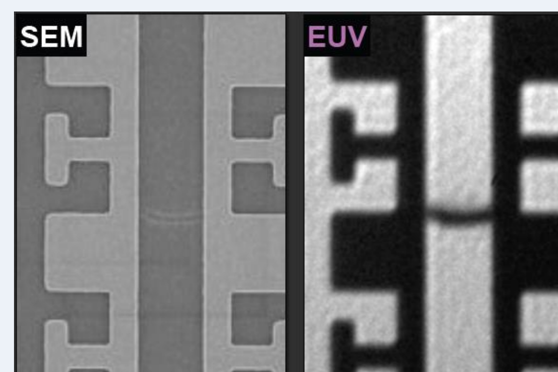


EUV Lithography Metrology

Measurement of mask – LWR, LER

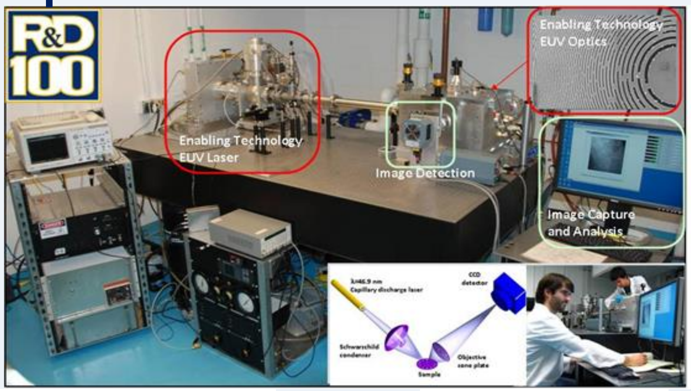


Characterization of native defects on a full field mask



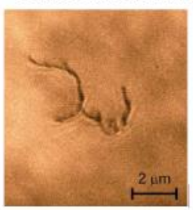
EUV ERC Overview: Nanoimaging

Compact Broad area EUV Microscopes



TRANSMISSION

50 nm carbon nanotube

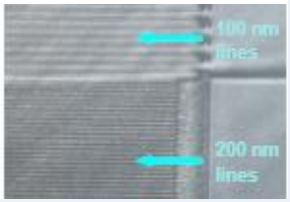


Spatial resolution: 54 nm

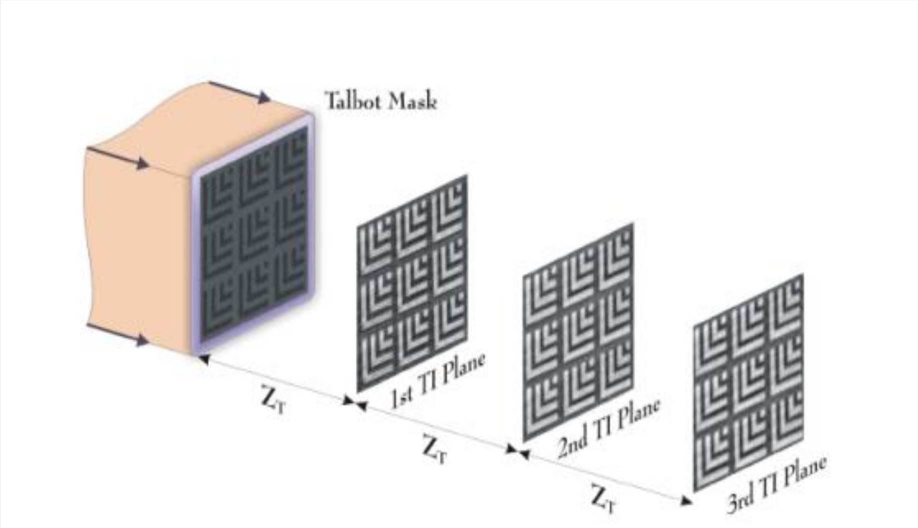
Image capture time: single laser shot

REFLECTION

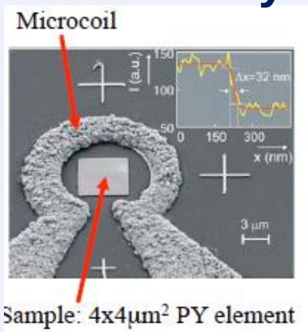
Integrated Circuit

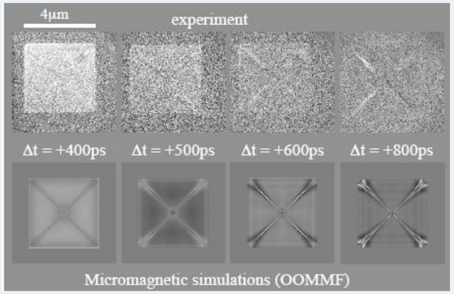


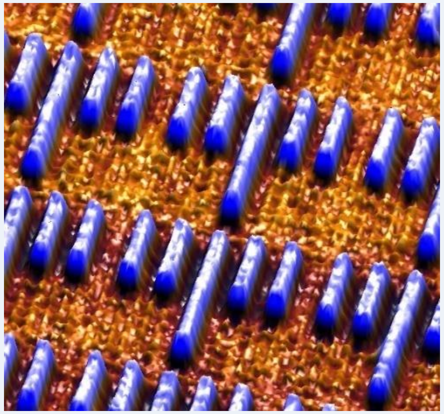
Imaging

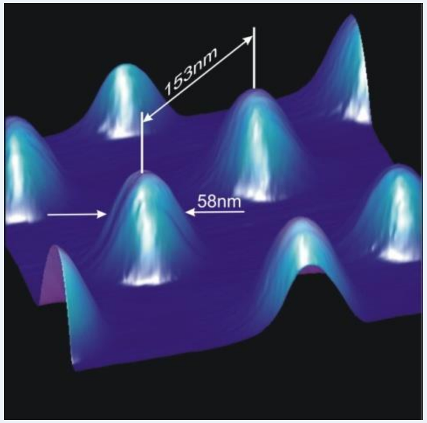


Imaging of magnetic spin dynamics with Synchrotron Light



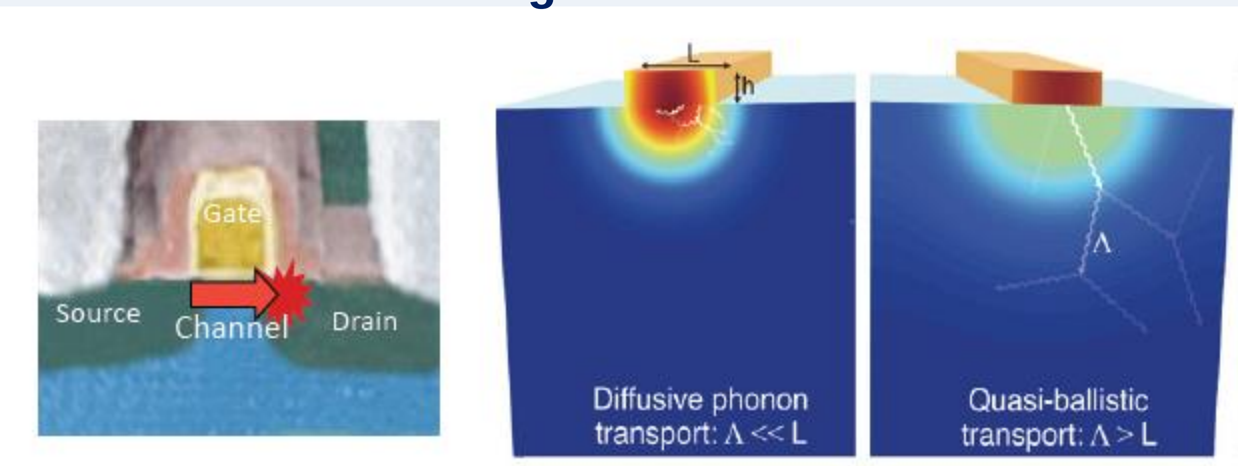




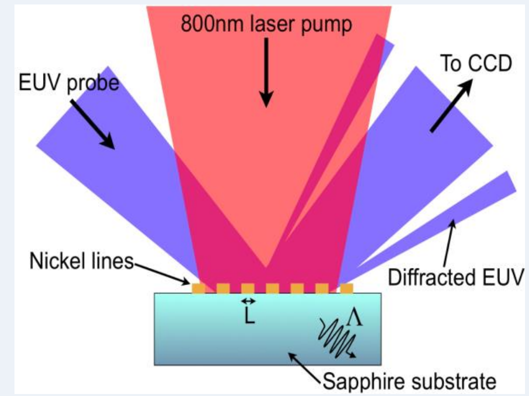


EUV ERC Overview: Nanoscale Materials Metrology

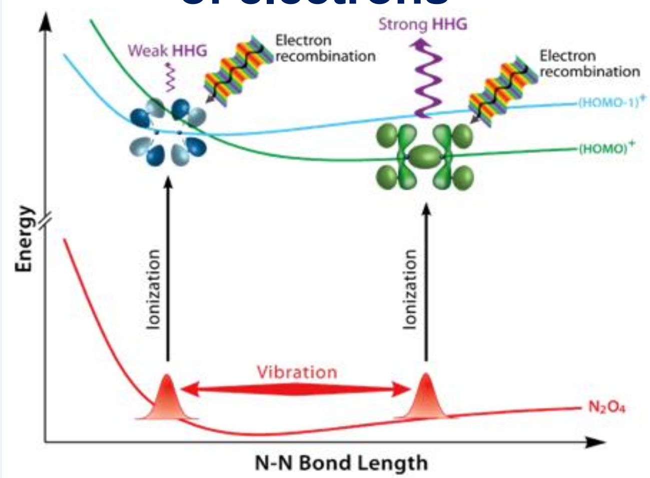
Characterizing heat flow at the nanoscale



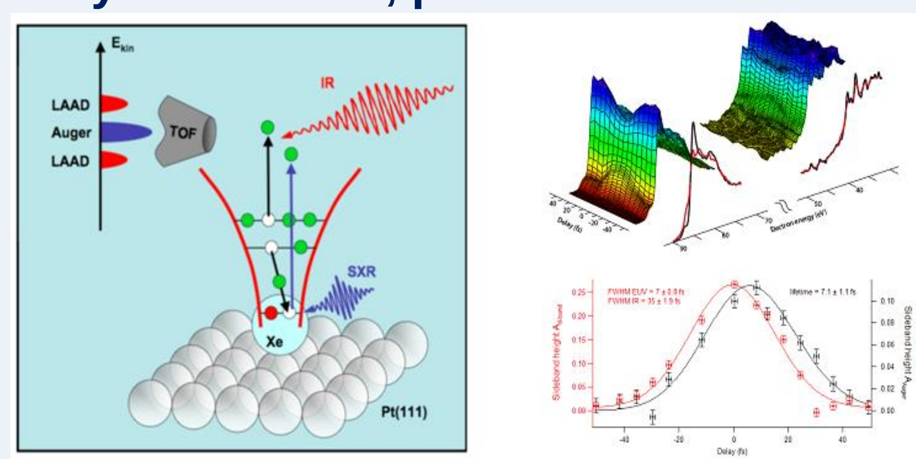
Acoustic metrology of thin films



Controlling reactions at the level of electrons

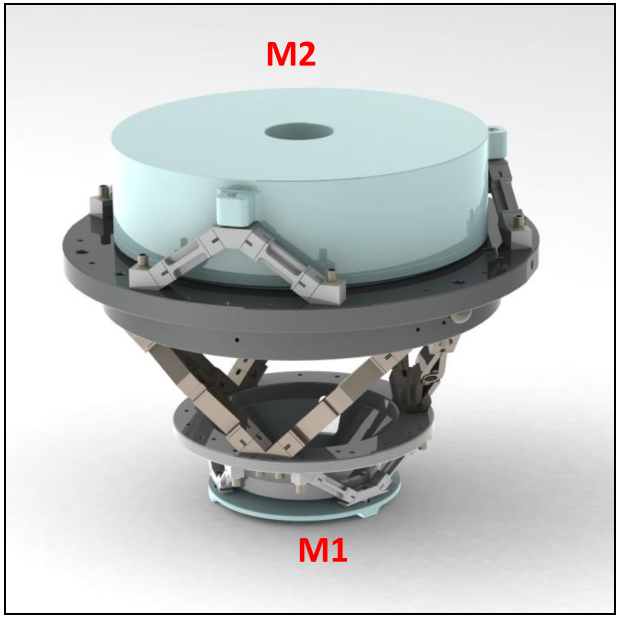


Understanding charge transfer on catalytic surfaces, photovoltaics

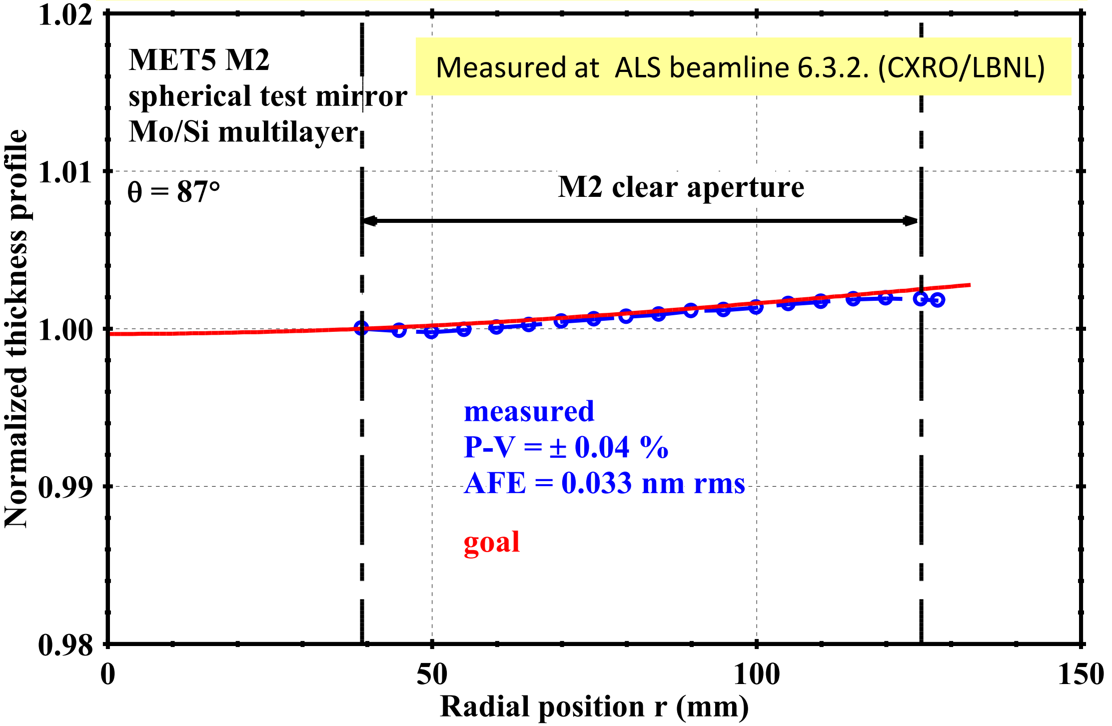


Development of multilayer projection mirrors for the first EUVL Micro-Exposure Tools with NA = 0.5 is underway

Opto-mechanical design of Projection Optics Box



M2 coating achieves ± 0.04 % peak-to-valley variation and 0.033 nm rms added-figure error over 250.8 mm-diameter clear aperture



H. Glatzel, D. Ashworth, M. Bremer, R. Chin, K. Cummings, L. Girard, M. Goldstein, E. Gullikson, R. Hudyma, J. Kennon, B. Kestner, L. Marchetti, P. Naulleau, R. Soufli, E. Spiller, Proc. SPIE **8679** 867917 (2013).

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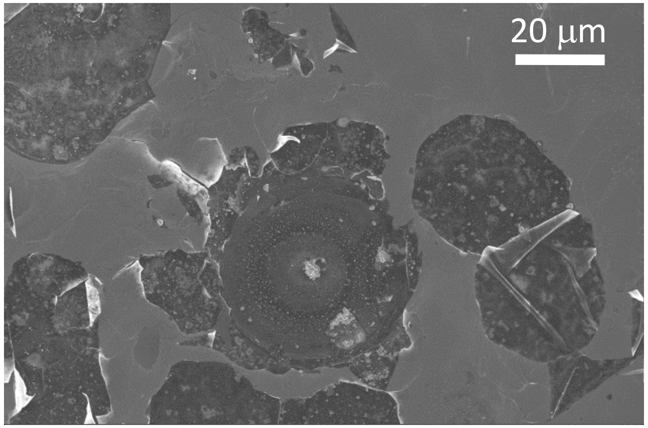
zygo

CXRO THE CENTER FOR X-RAY OPTICS

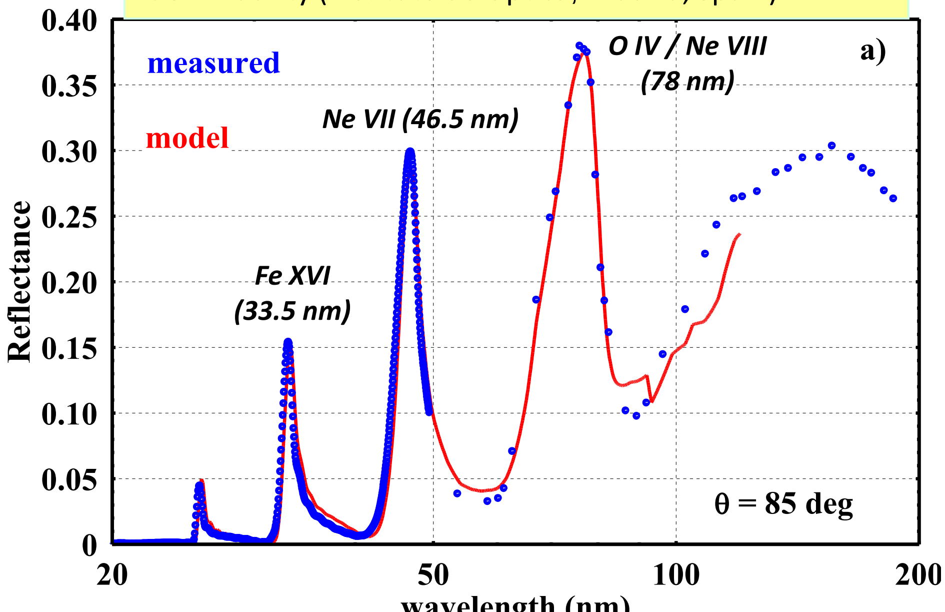
BERKELEY LAB

Triple-wavelength Mg/SiC multilayer coatings with corrosion barriers have been developed for EUV laser sources in the 25-80 nm wavelength region

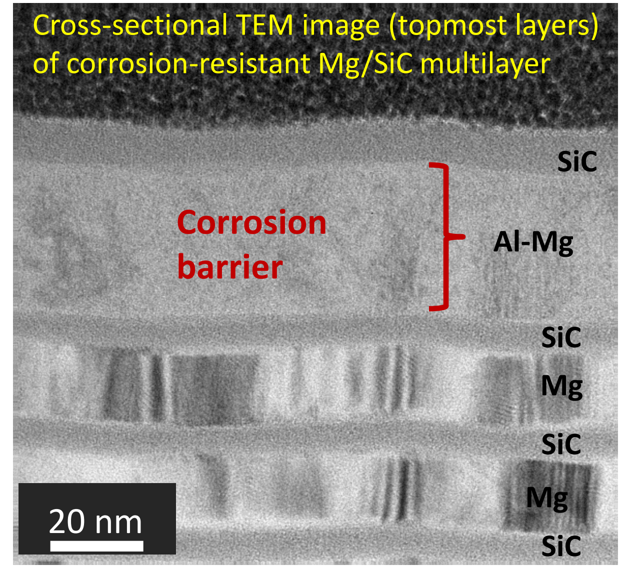
Top-surface SEM image of standard Mg/SiC multilayer mirror with advanced corrosion



Measured at ALS beamline 6.3.2. (CXRO/LBNL) and at the GOLD facility (Instituto de Óptica, Madrid, Spain).



Spontaneously intermixed Al-Mg corrosion barriers enable use of Mg-based multilayers



- R. Soufli, M. Fernández-Perea, S. L. Baker, *et al*, App. Phys. Lett. **101**, 043111 (2012).
- M. Fernández-Perea, R. Soufli, J. C. Robinson, *et al*, Optics Express **20**, 24018-24029 (2012).

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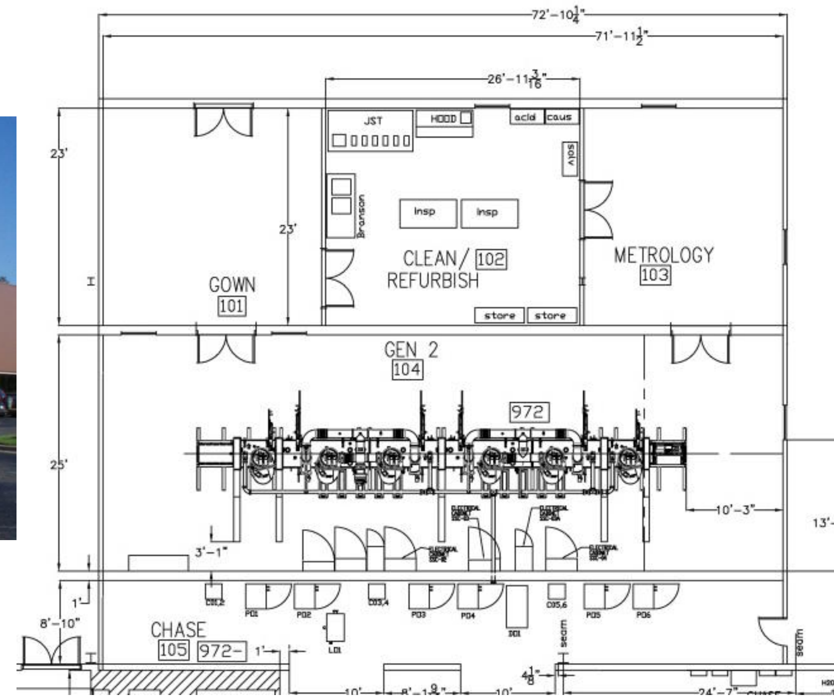
Rigaku Innovative Technologies (RIT)

Investing \$9M+ this year to establish & qualify scalable HVM EUVL Optic Pilot Production Facility – commissioning ~Oct 2013

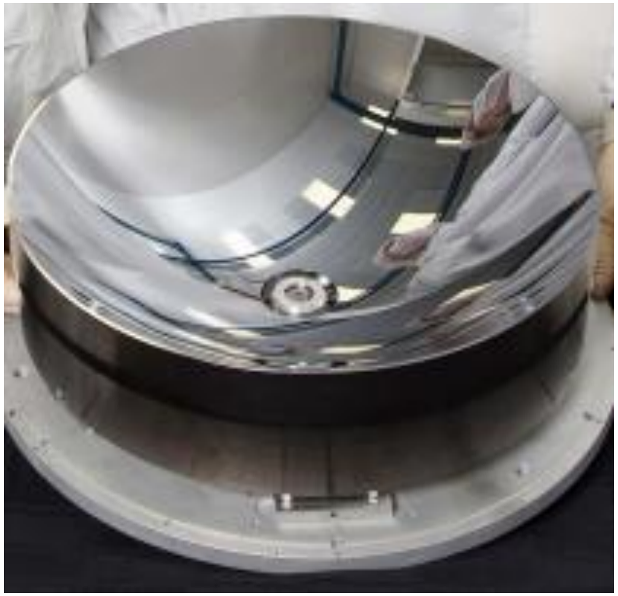
- Second Generation Inline Deposition Tool,
- In-house actinic metrology
- cleaning/refurbishment facilities

~4000 ft^2 cleanrooms

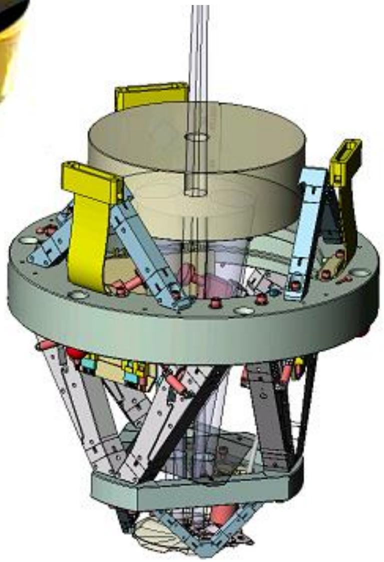
Auburn Hills, MI



RIT- Current Development Activities



1. Collectors for High Power Sources
    - Volume Productivity
    - Refurbishment of Used Optics; reduced CoO
    - Cap Layer optimization
    - IR mitigation

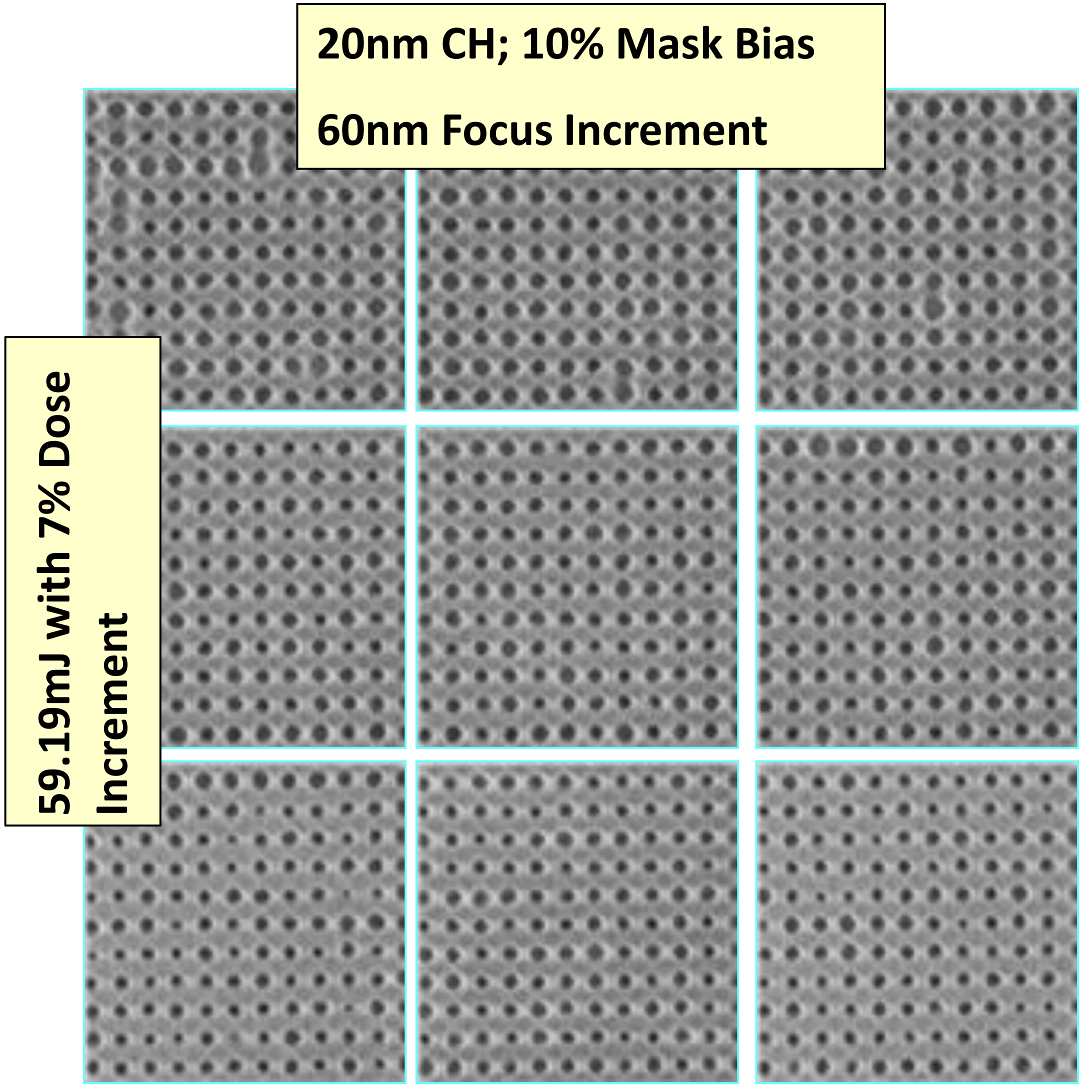


2. Illumination & Imaging Optics
    - Refurbishment of Contaminated Optics
    - High Gradient (NA) multilayers

3. R&D (basic)
    - Increased reflectivity, 6.x

Rigaku

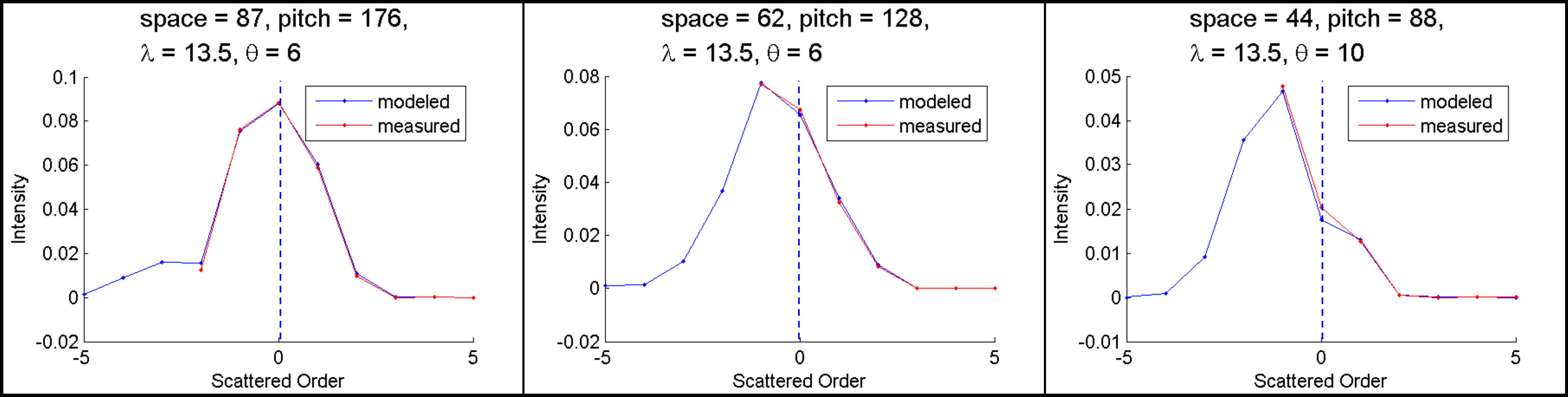
New champion contact results



	10% Mask Bias	20% Mask Bias
30nm CH	34.11mJ/cm^2	27.75mJ/cm^2
28nm CH	36.93mJ/cm^2	27.58mJ/cm^2
26nm CH	41.24mJ/cm^2	30.43mJ/cm^2
24nm CH	46.73mJ/cm^2	33mJ/cm^2
22nm CH	51.37mJ/cm^2	36.07mJ/cm^2
20nm CH	60.61mJ/cm^2	41.76mJ/cm^2
18nm CH	83.9mJ/cm^2	64mJ/cm^2

SEMATECH Berkeley MET
Quadrupole illumination

Characterization of large order asymmetry in high NA diffraction

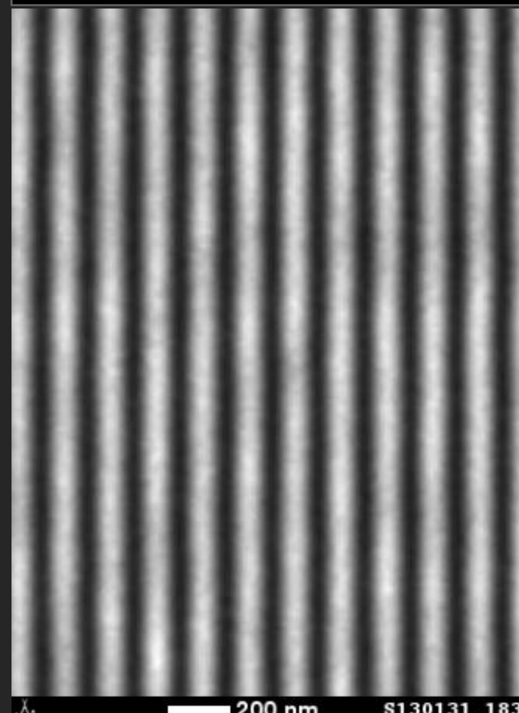


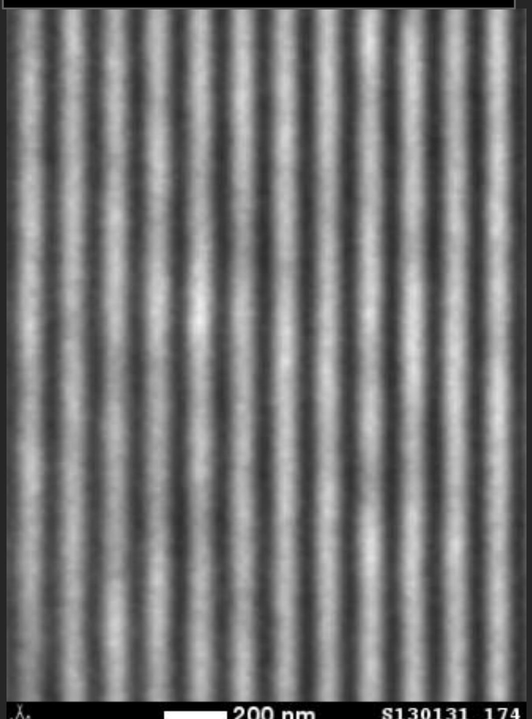
- Effect well captured with rigorous 3D modeling including interface roughness term

New SEMATECH-Berkeley mask inspection tool (SHARP) operational

150x faster
2x higher resolution

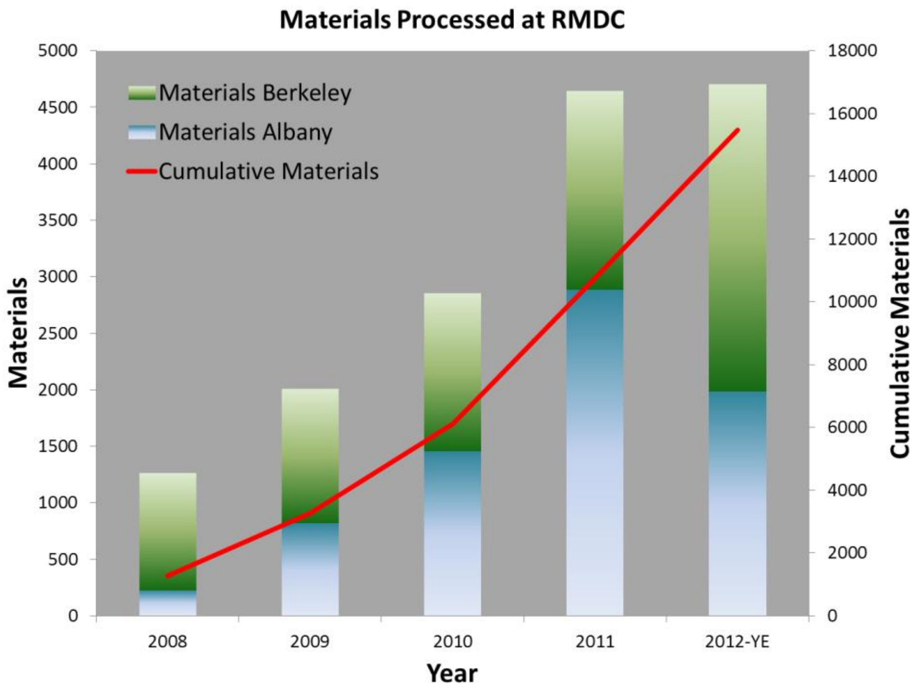
65-nm hp (16.25)	60-nm hp (15.00)	55-nm hp (13.75)

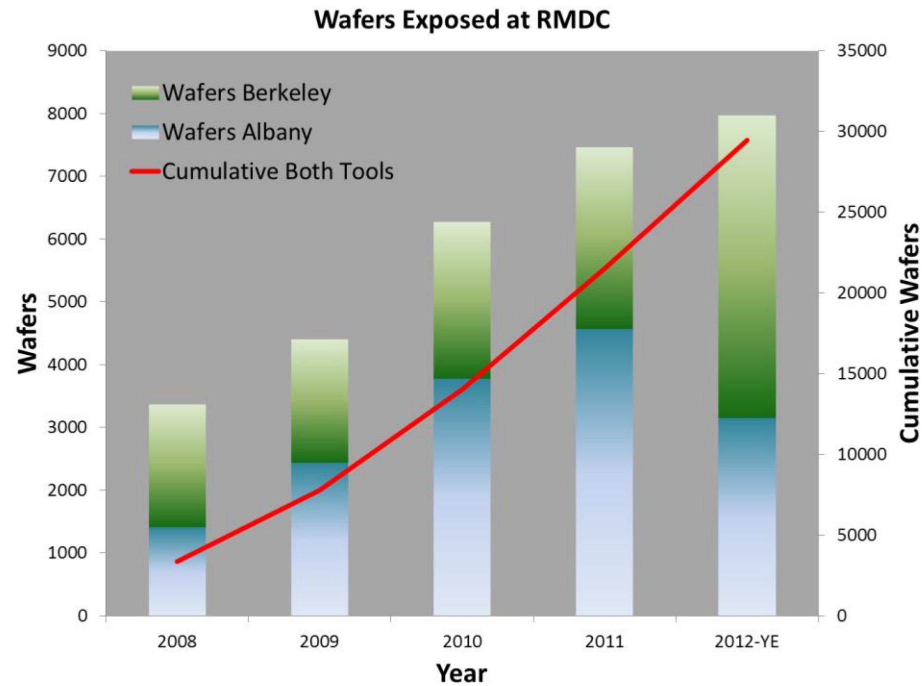




Rapid industry *Resist Learning Cycles* are critical to enable HVM EUV resist performance

SEMATECH RMDC Materials & Wafer Processing Records

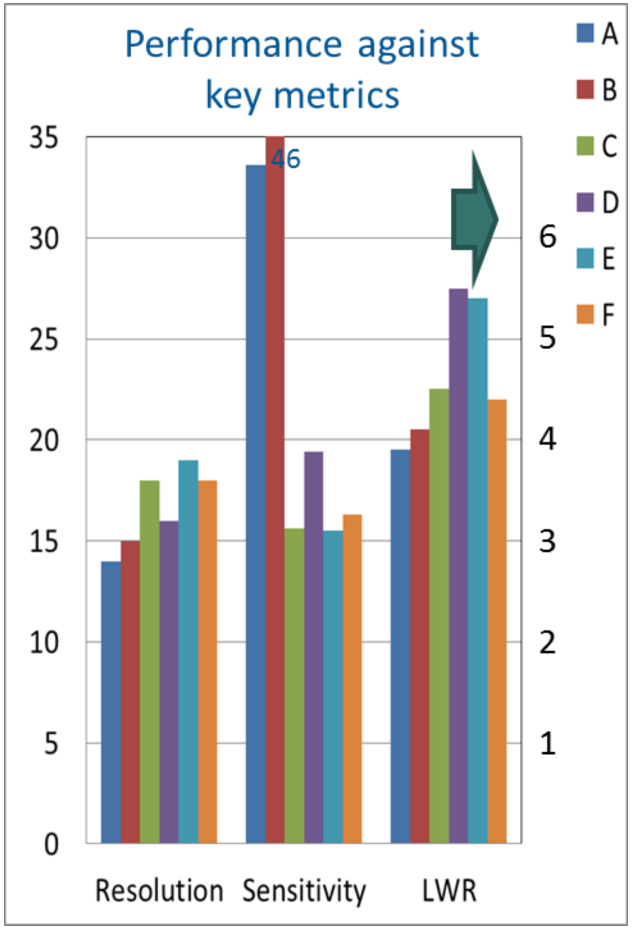




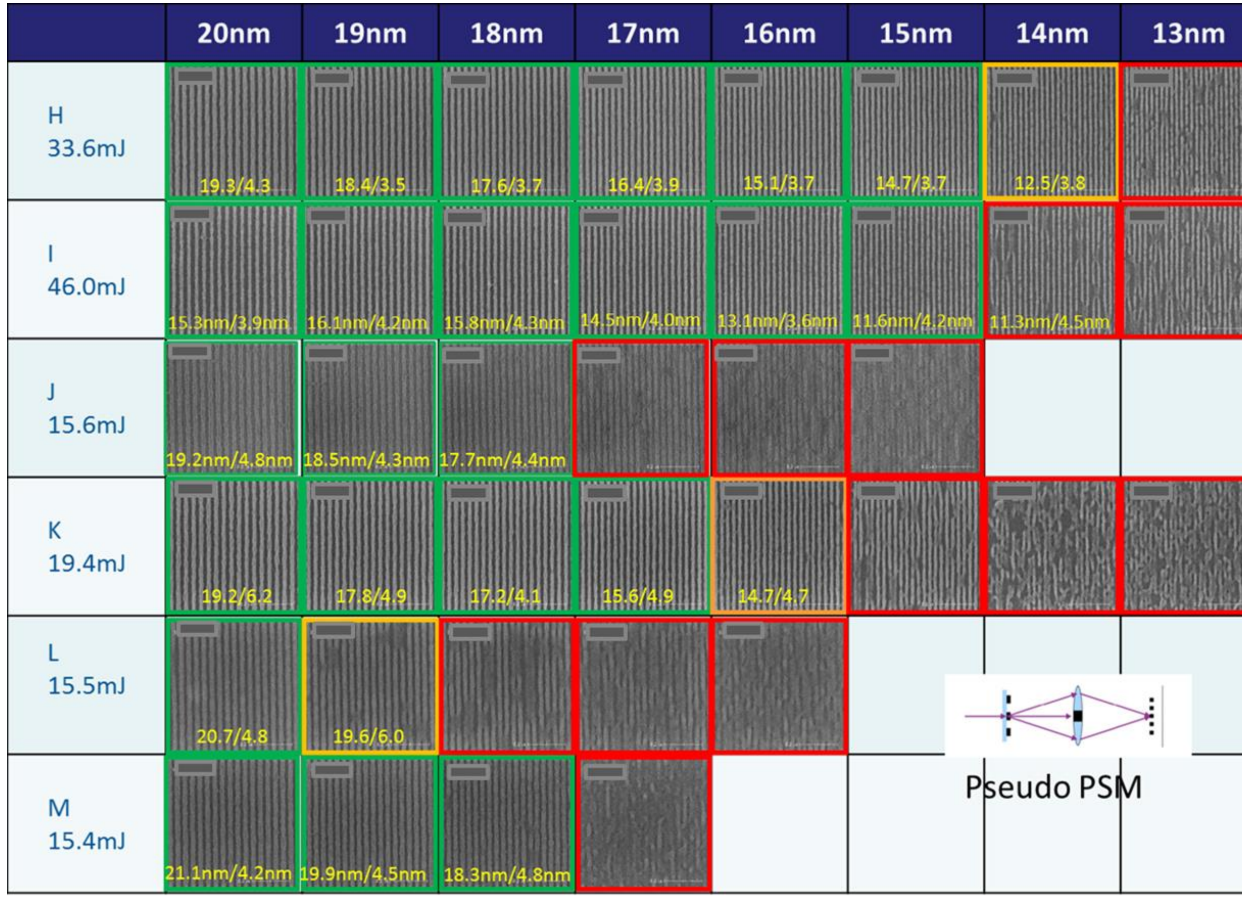
- >15000 materials and >29000 wafers have been processed at SEMATECH’s Resist and Materials Development Center (RMDC) since 2008 (Albany MET & LBNL MET)
- In 2012, 4703 materials (1981 Albany MET, 2722 LBNL MET) and 7972 wafers were processed (3153 Albany MET, 4819 LBNL MET)

L/S EUV Resist Performance Status

Pseudo PSM @ SEMATECH's Tool in Berkeley



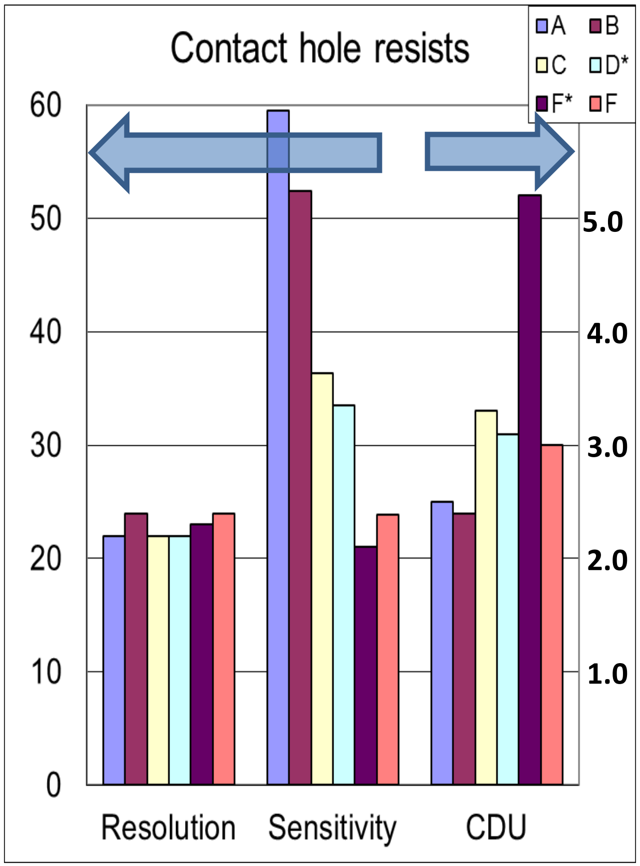
- Berkeley MET, PPSM
- 30nm Resist THK



Best resist for each supplier

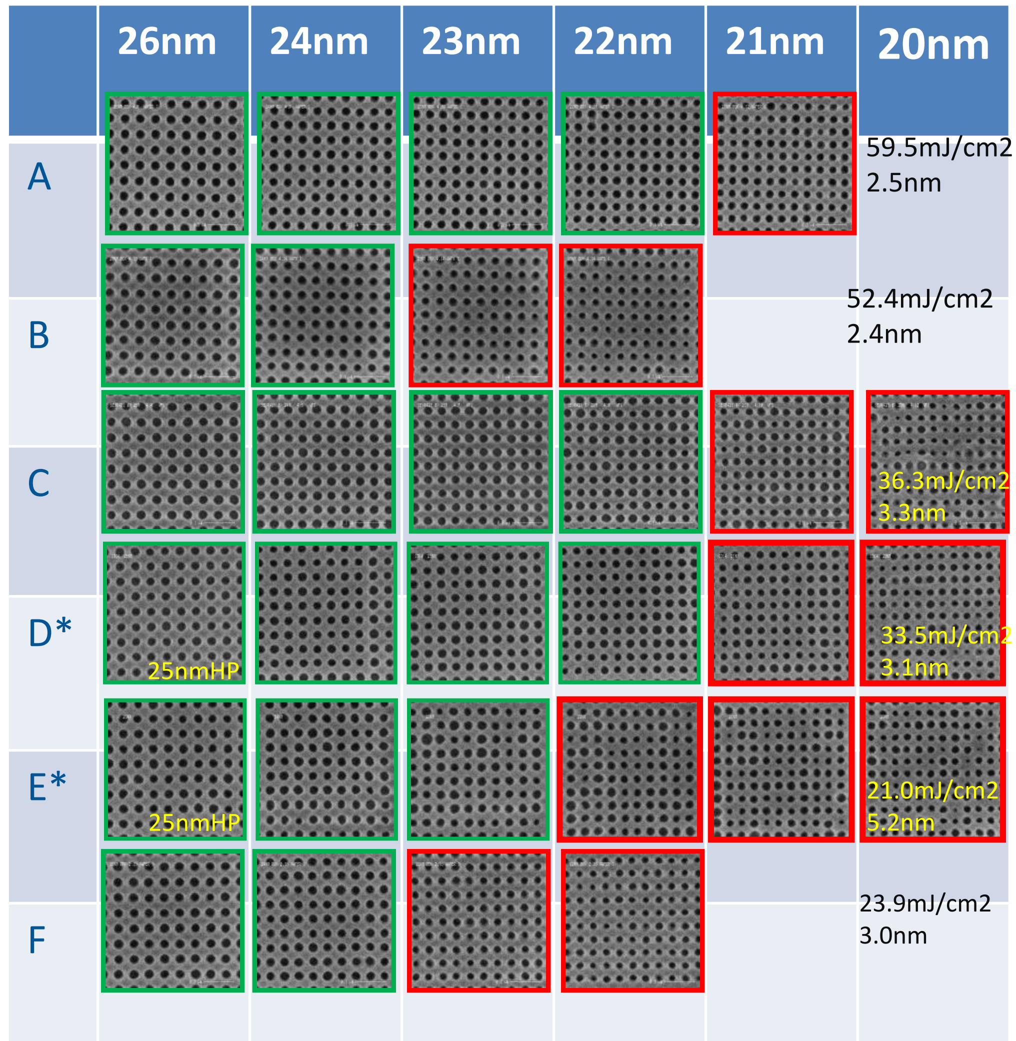
C/H EUV Resist Performance Status

SEMATECH Berkeley MET: Quad, NA 0.3, sigma 0.48~0.68;
FT 80nm (A,B,C,F); 60nm; D, E
No mask bias (A,B,C,F) (+20% Bias)

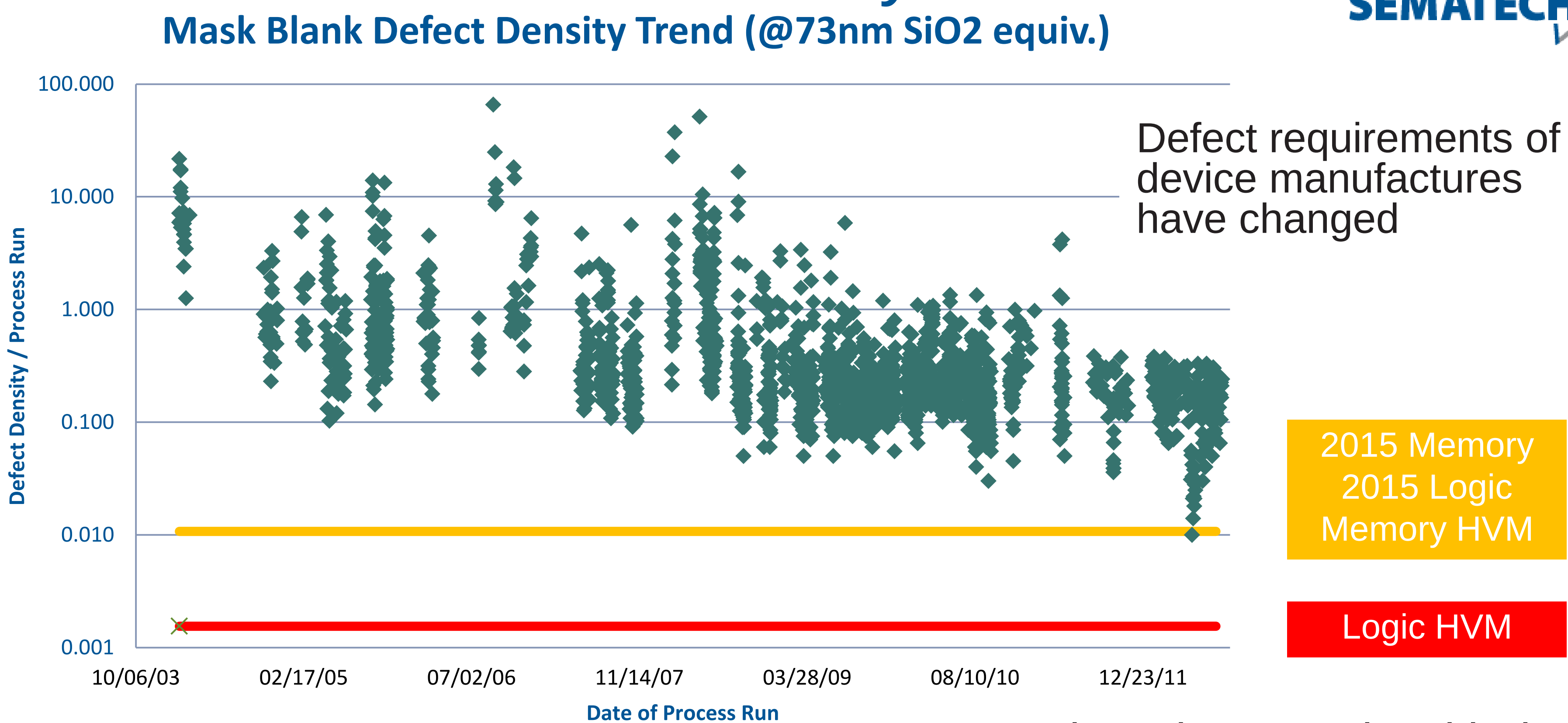


* CDU was measured at 26nm HP

D*, E*: 60 nm FT & +20% bias



Mask Blank Defect Density Trend

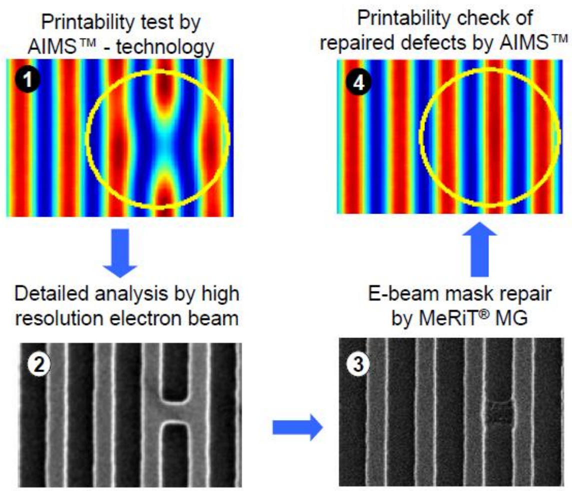


- 2015
  - Overall defect counts should meet requirements
  - Large size “Killer” defects still present
- HVM
  - Significant improvement needed to meet logic specifications
- Recent gains where made with the substrate
  - Reduction of cleaning induced defects
  - Substrate quality improvement at suppliers
- Process yields are not good

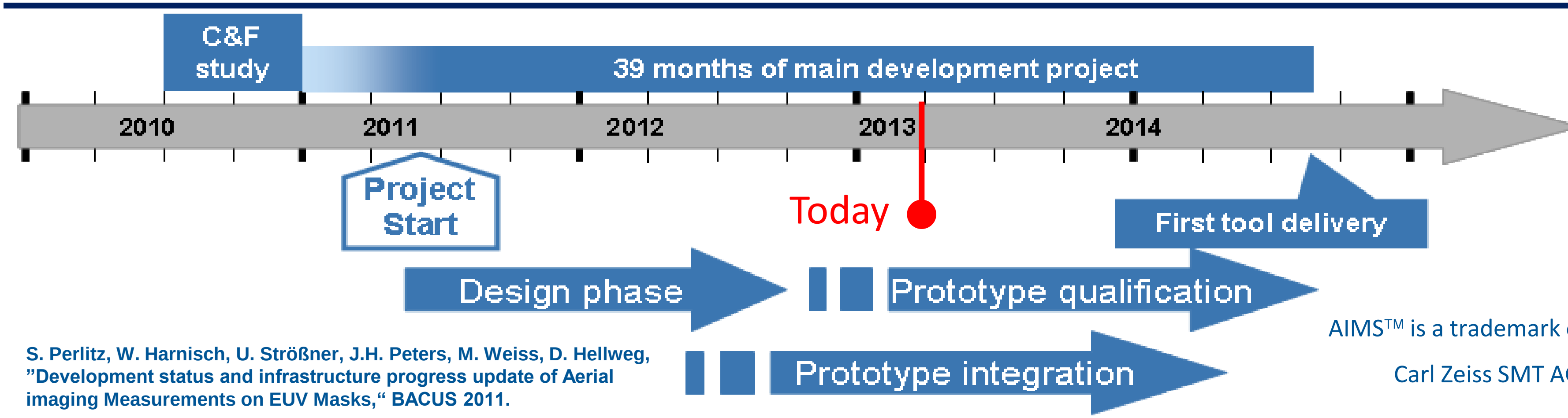
SEMATECH – Zeiss AIMS^{TM} collaboration

Enabling EUV Mask Tool Infrastructure

- Zeiss AIMS^{TM} EUV project started 05/2011 is on track
- Five EMI members are participating



D.Hellweg, J.Ruoff, A.Herkommer, H.Feldmann, M.Ringel, U.Strößner, S.Perlitz, W.Harnisch, "Actinic aerial image review of EUV masks," Proc of SPIE 7969-15 (2011).

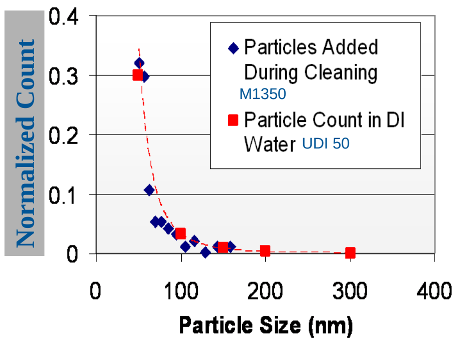


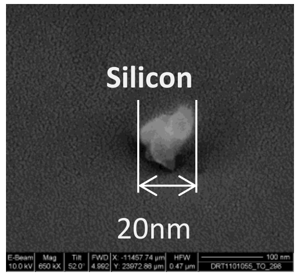
S. Perlitz, W. Harnisch, U. Strößner, J.H. Peters, M. Weiss, D. Hellweg, "Development status and infrastructure progress update of Aerial imaging Measurements on EUV Masks," BACUS 2011.

AIMS^{TM} is a trademark of Carl Zeiss SMT AG.

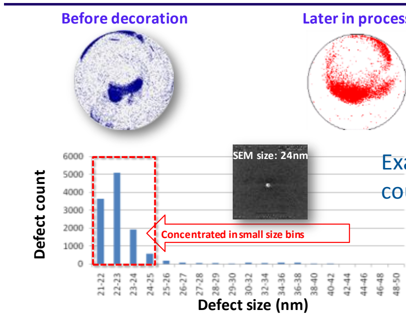
Nanodefect Problem

Nanodefects Exist
Nanoscale materials structure generates nanosize problems

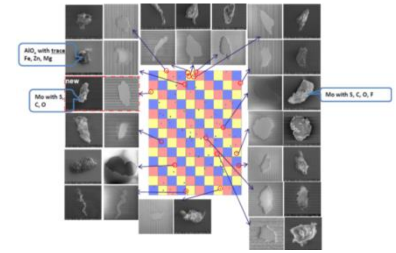




Nanodefects are hard to find
Below the threshold of most detection schemes

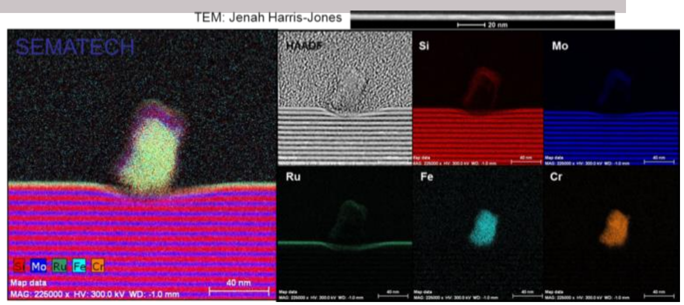


Example courtesy of KLA

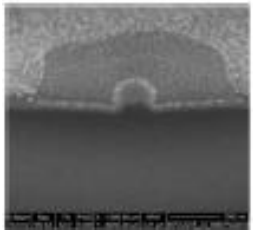


SEMATECH MBDC data

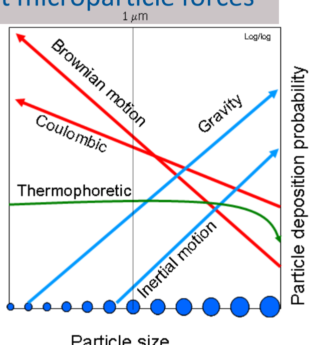
Nanodefects are difficult to characterize
Requires $10'sM of difficult equipment



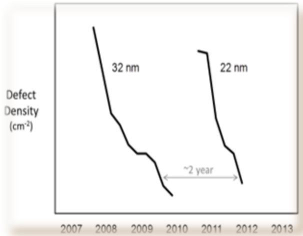
Nanodefects are difficult to remove
Nanoparticle forces are not microparticle forces



30nm SiO_2 particle on surface

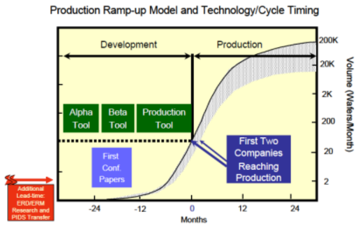


Increasing pressure on yield learning



From S. Johnston, SEMATECH Japan Symposium 2012

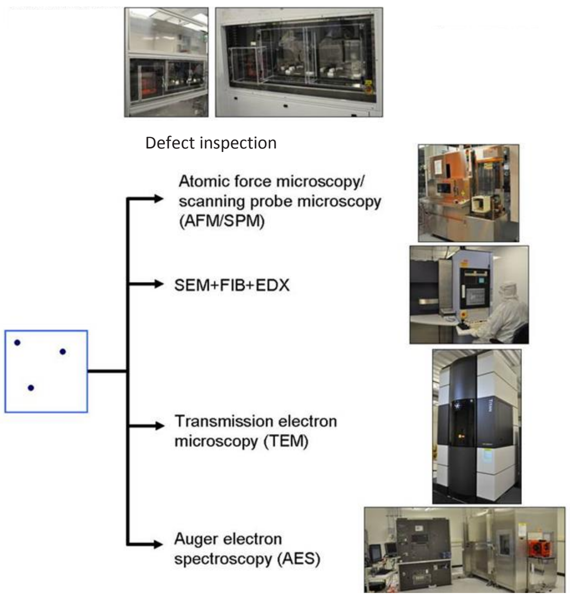
Increasing pressure on supply chain
Yield learning must continue but cost of doing so increases



NanoDefects: The Solution

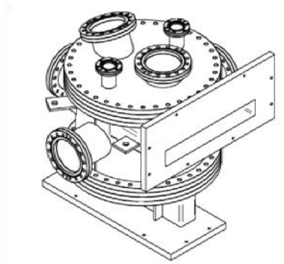
Collaborate

Provide a common facility for the required critical expensive infrastructure

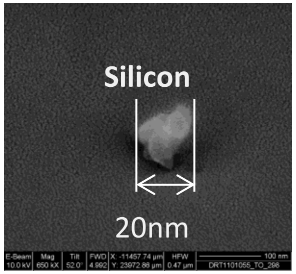


Work Proactively

Break the problem down and solve component and material problems before integration

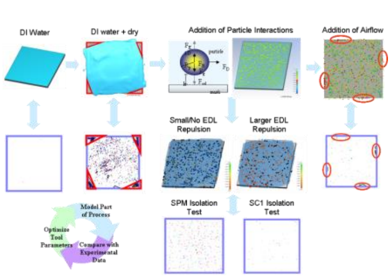


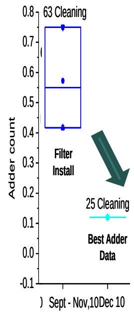
Component level accelerated life test



Drive Solutions

Based on fundamental science of the defect problem





Understand the physics, model the problem, and make a solution

SEMATECH Nanodefect Center